WG 1 Summary

FNAL Proton Driver Workshop
October 9, 2004

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Session I

Purpose and setting of scene

Neutrino oscillations as probes of GUT theories (Andre de Gouvea)

$\Delta m^2_{13} > 0$ "typical" prediction of all* Type-I GUT models

inverted hierarchy requires* "more flavor structure"

*Albright, hep-ph/0407155

Reference	$\sin\theta_{13}$	$\sin^2 2\theta_{13}$
SO(10)		
Goh, Mohapatra, Ng [40]	0.18	0.13
Orbifold SO(10)		
Asaka, Buchmüller, Covi [41]	0.1	0.04
SO(10) + flavor symmetry		
Babu, Pati, Wilczek [42]	$5.5\cdot10^{-4}$	$1.2\cdot10^{-6}$
Blazek, Raby, Tobe [43]	0.05	0.01
Kitano, Mimura [44]	0.22	0.18
Albright, Barr [45]	0.014	$7.8\cdot10^{-4}$
Maekawa [46]	0.22	0.18
Ross, Velasco-Sevilla [47]	0.07	0.02
Chen, Mahanthappa [48]	0.15	0.09
Raby [49]	0.1	0.04
SO(10) + texture		
Buchmüller, Wyler [50]	0.1	0.04
Bando, Obara [51]	0.01 .. 0.06	$4\cdot10^{-4}$ .. 0.01
Flavor symmetries		
Grimus, Lavoura [52, 53]	0	0
Grimus, Lavoura [52]	0.3	0.3
Babu, Ma, Valle [54]	0.14	0.08
Kuchimanchi, Mohapatra [55]	0.08 .. 0.4	0.03 .. 0.5
Ohlsson, Seidl [56]	0.07 .. 0.14	0.02 .. 0.08
King, Ross [57]	0.2	0.15
Textures		
Honda, Kaneko, Tanimoto [58]	0.08 .. 0.20	0.03 .. 0.15
Lebed, Martin [59]	0.1	0.04
Bando, Kaneko, Obara, Tanimoto [60]	0.01 .. 0.05	$4\cdot10^{-4}$ .. 0.01
Ibarra, Ross [61]	0.2	0.15
3 × 2 see-saw		
Appelquist, Piai, Shrock [62, 63]	0.05	0.01
Frampton, Glashow, Yanagida [64]	0.1	0.04
Mei, Xing [65] (normal hierarchy)	0.07	0.02
(inverted hierarchy)	> 0.006	$> 1.6\cdot10^{-4}$
Anarchy		
de Gouvêa, Murayama [66]	> 0.1	> 0.04
Renormalization group enhancement		
Mohapatra, Parida, Rajasekaran [67]	0.08 .. 0.1	0.03 .. 0.04

Table 1: Incomplete selection of predictions for θ_{13}. The numbers should be considered as order of magnitude statements.

[from reactor white paper]

The literature on this subject is very large. The most exciting driving force (my opinion) is the fact that one can make *bona fide* predictions:

$\Rightarrow U_{e3}$, CP-violation, mass-hierarchy unknown!

Unfortunately, theorists have done too good a job, and people have successfully predicted everything...

More data needed to "sort things out," which is why we are here!

Also: Mass hierarchy, deviations from max. mixing!

Relationship to Low Energy Observables?

In general …no. This is very easy to understand. The baryon asymmetry depends on the (high energy) physics responsible for lepton-number violation. Neutrino masses are one of many consequences of this physics, albeit the only observable ones at the "low-energy" experiments we are able to perform.

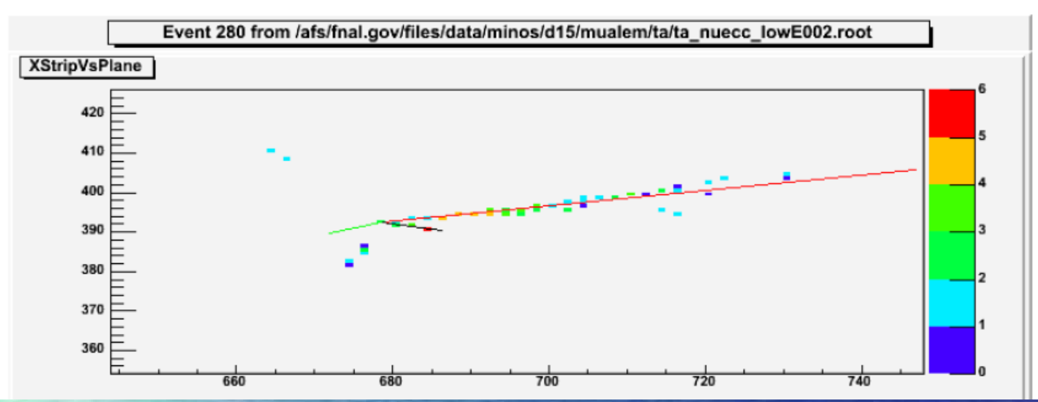
see-saw: y, M_N have more physical parameters than $m_\nu = y^t M_N^{-1} y$.

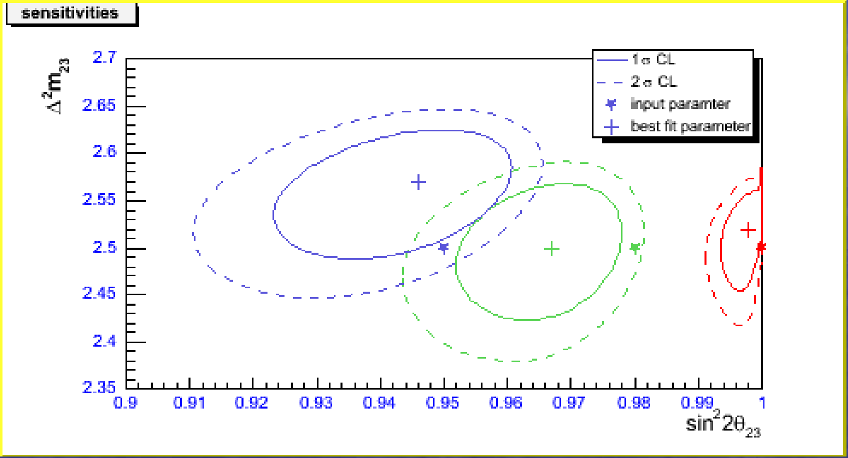
There could be a relationship, but it requires that we know more about the high energy Lagrangian (model depent). The day will come when we have enough evidence to refute leptogenesis (or strongly suspect that it is correct) - but more information is really necessary (charged-lepton flavor violation, collider data on EWSB, lepton-number violation, precise oscillation parameter measurements,etc).

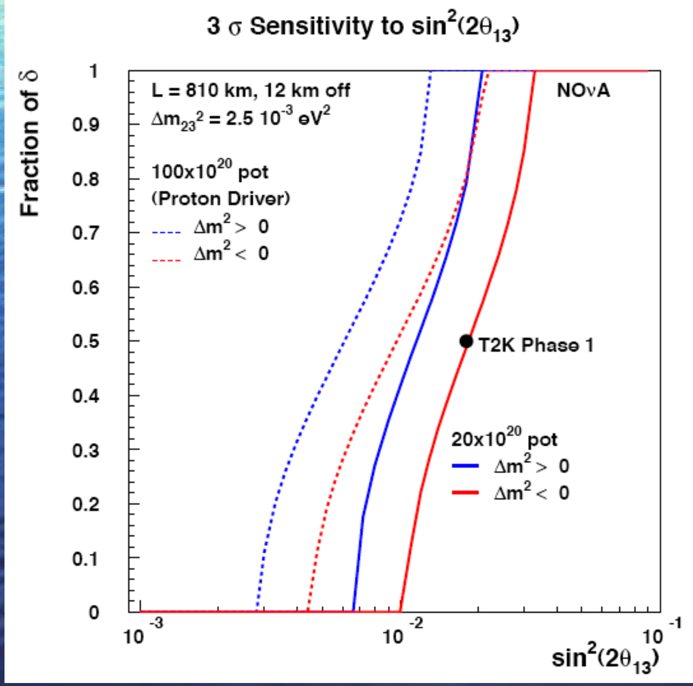
Session II

Superbeam Experiments I

NOνA Vital Statistics (Feldman)





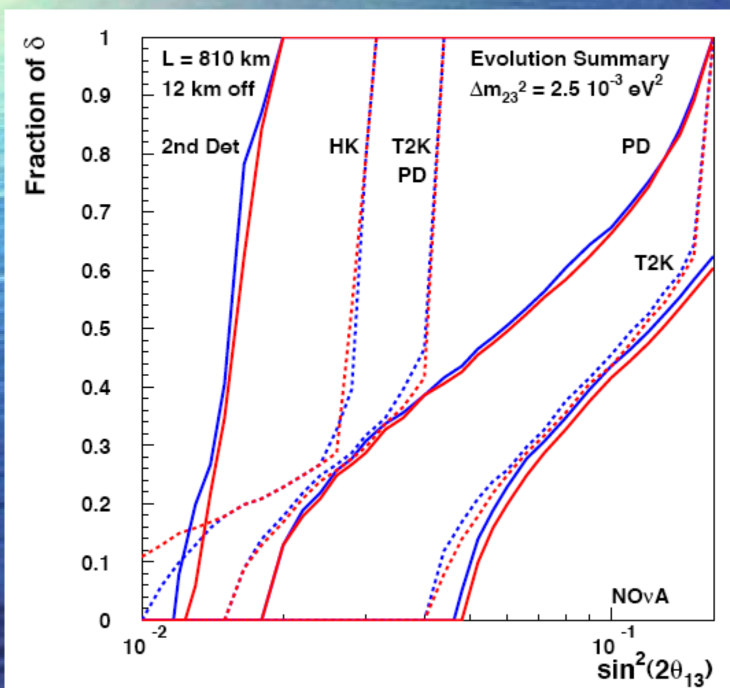


	Baseline	TASD
Mass	50 kT	25 kT
Optimized ν_e efficiency	18%	32%
Optimized s/b	4.8	7.7
s/sqrt(b)	24.5	24
Cost	$147M	$159M

NOνA and the Proton Driver

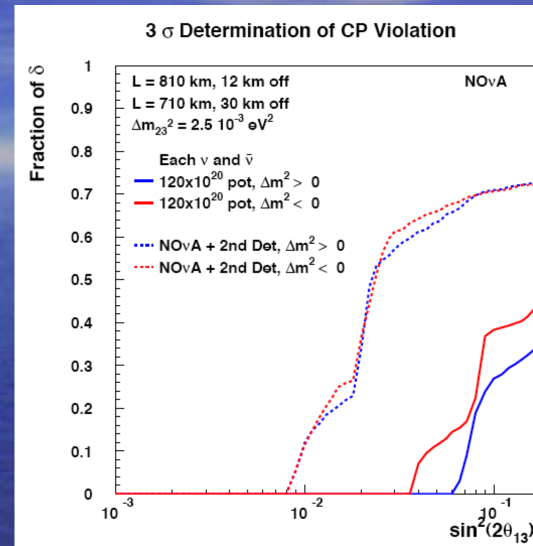
Note that a Proton Driver changes a 1σ matter effect into a 3σ effect:

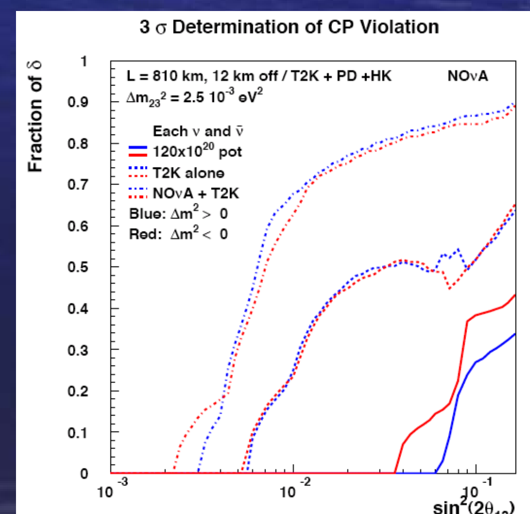
$\Delta\chi^2 = 2.3 \rightarrow \Delta\chi^2 = 11.8.$



2σ Mass Hierarchy

3σ CP violation: 2nd detector and T2K synergy



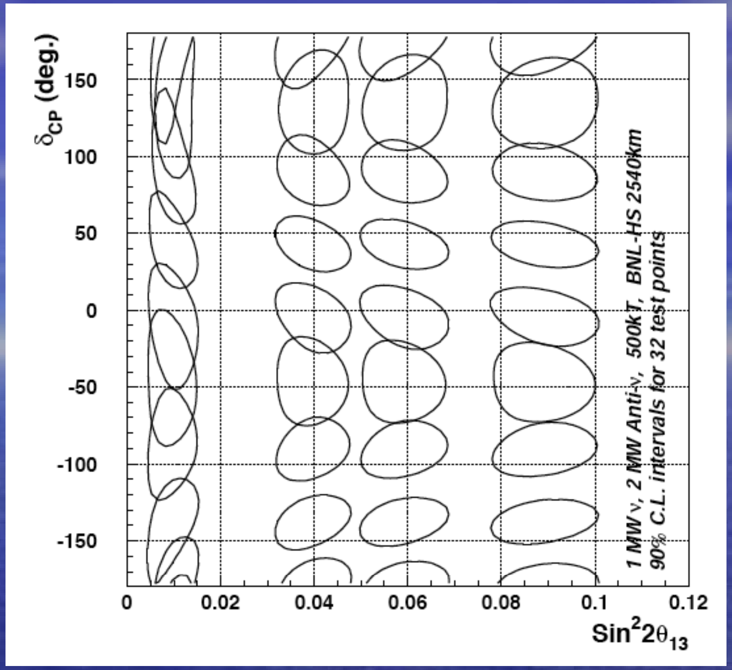


Comparing Super-NOνA and BNL

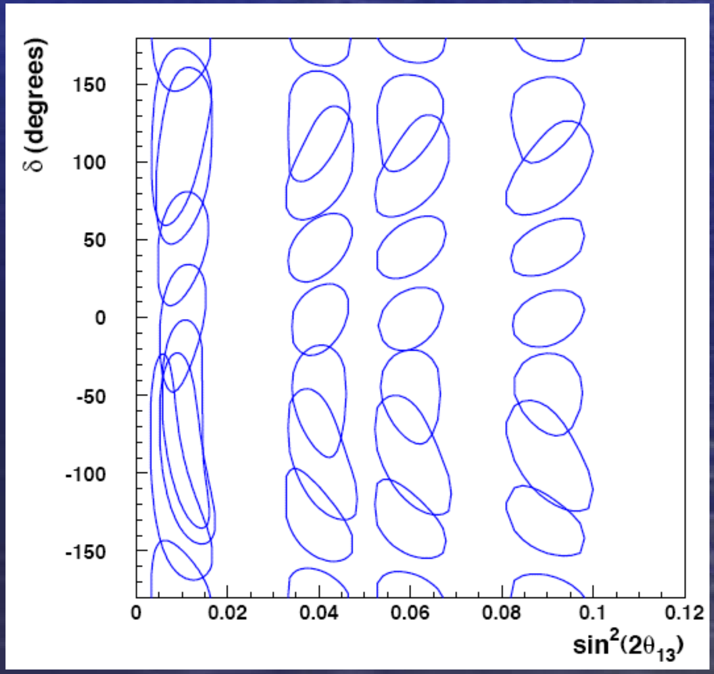
Vigorous discussion:

- BNL proposal is not so different in MW*kton than the NOνA+PD+2nd Det listed here
- BNL Advantage: they can see "solar term" even if $\sin^2 2\Theta_{13}=0$; synergy w/p decay
- NOνA+PD+2nd Det advantage: can proceed in a step-by step manner

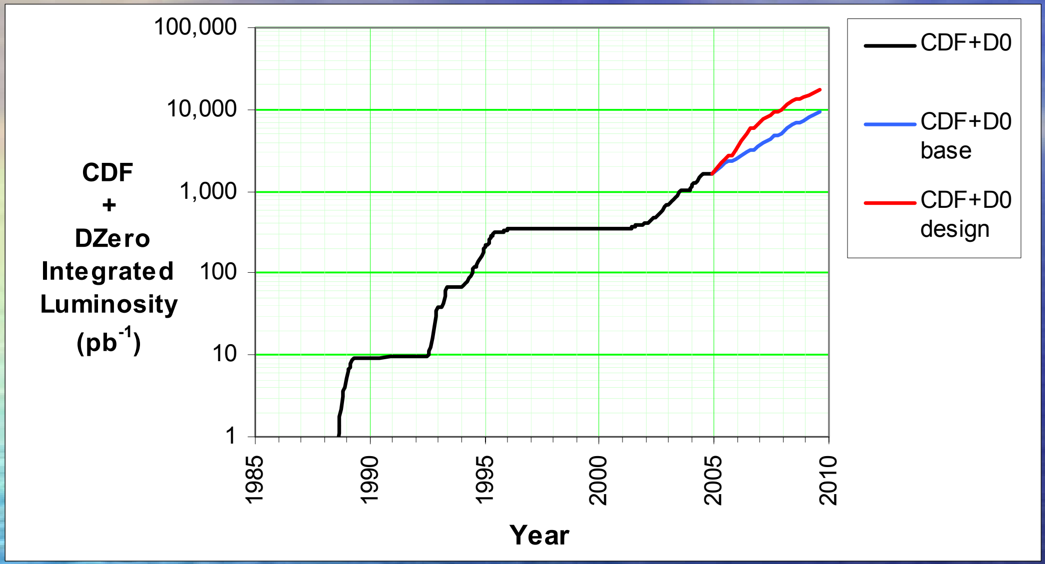
BNL Proposal



NOνA + PD + 2nd Det

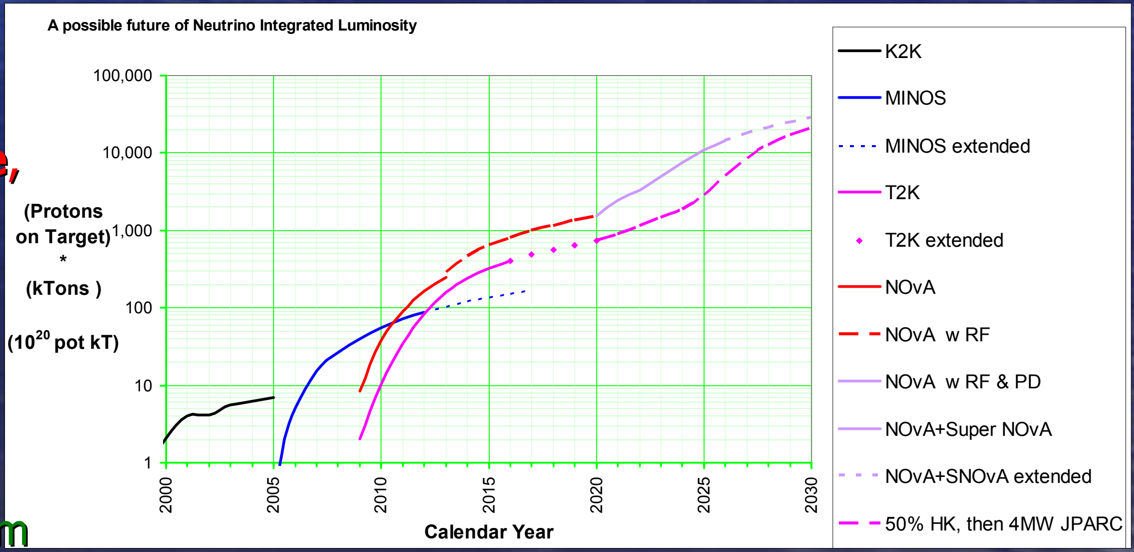


Collider/Neutrino Program Analogy (Cooper)



- **Integrated Luminosity doubles 14 times in 21 years (1988-2009)**
  - (2^{14}=16,384), Integrated Luminosity advances by 3+ orders of magnitude
- **The original 87 CDF collaborators grew to 1500 total at CDF + DZero**

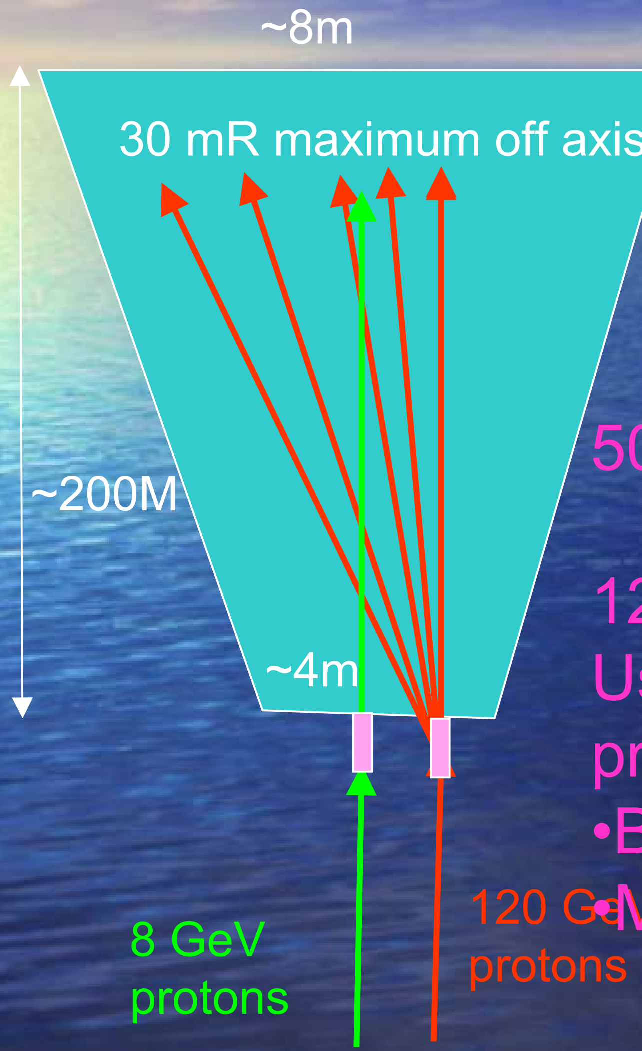
- MINOS is 10* K2K
- **Add NOνA,** 5 * MINOS ktons
- **Add a Main Injector RF upgrade,** 2 * NuMI pot
- **Add a Proton Driver** 5 * (NuMI + MI RF) pot
- **Add SuperNOνA,** 3 * NOνA ktons
- Overall, can get a factor >1000 (in 10^{20} pot * kT) in such a program



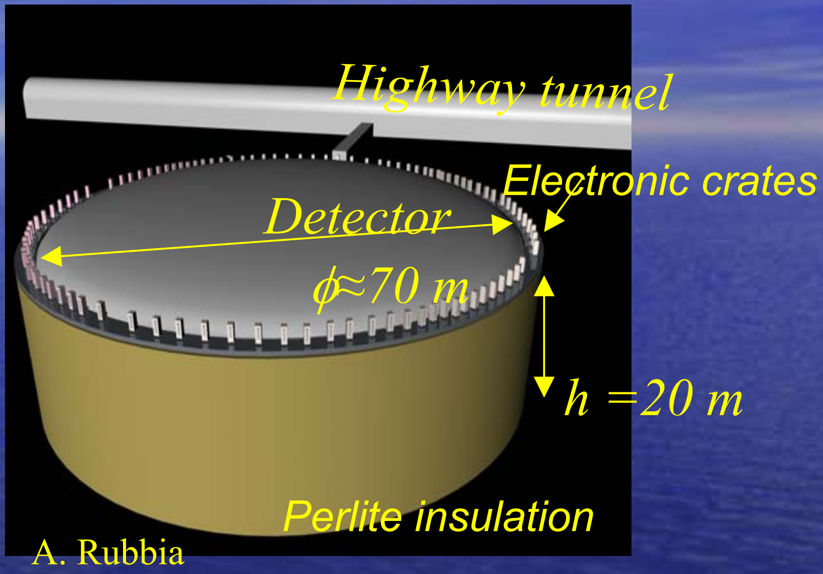
Ah, but aren't colliders just richer than "measure one number" ν physics?

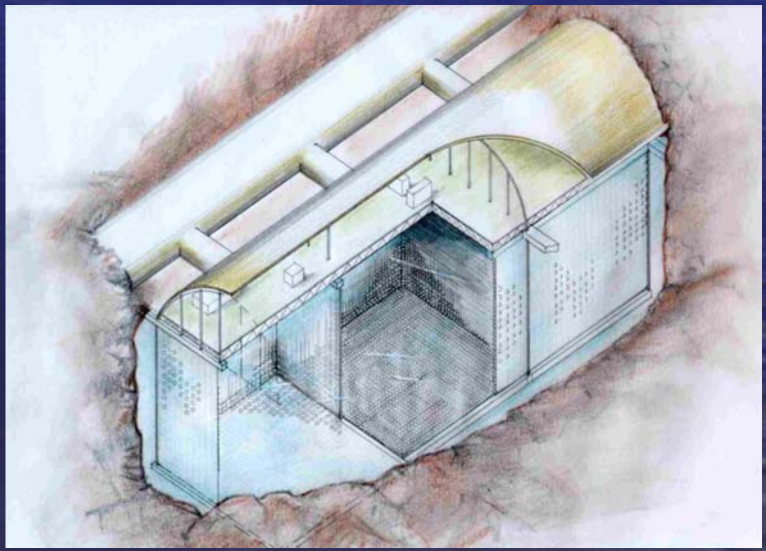
- **NO – While θ_{13} is the driving goal,** we should not start to think of θ_{13} like we did about the Higgs as the only justification of a program
  - Measuring θ_{13} is like finding and measuring the top mass?
  - Determining the mass hierarchy is like a Higgs discovery?
  - Detection of <u>CP violation</u> in the neutrino sector is like finding SUSY ?
  - **There are other physics topics**
    - Measuring $\sin^2\theta_{23}$ and $\Delta m_{23}{}^2$ at each new level of luminosity is like measuring the W mass or B lifetimes <u>at each new level of luminosity</u> in the collider program
    - Searching for sterile neutrino effects <u>at each new level of luminosity</u> is like searching for Z' at each new level of luminosity
    - Measuring low energy ν cross sections (DIS, quasi-elastic,…) is (like) studying QCD
    -
    -
- **There should be plenty of ν publications!!!**

Fermilab to Homestake (2+2)MW (D. Michael)

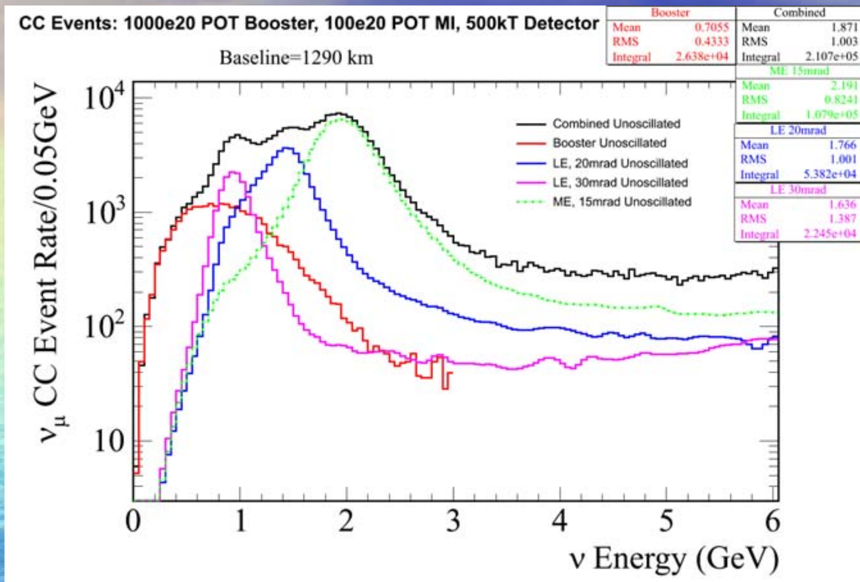


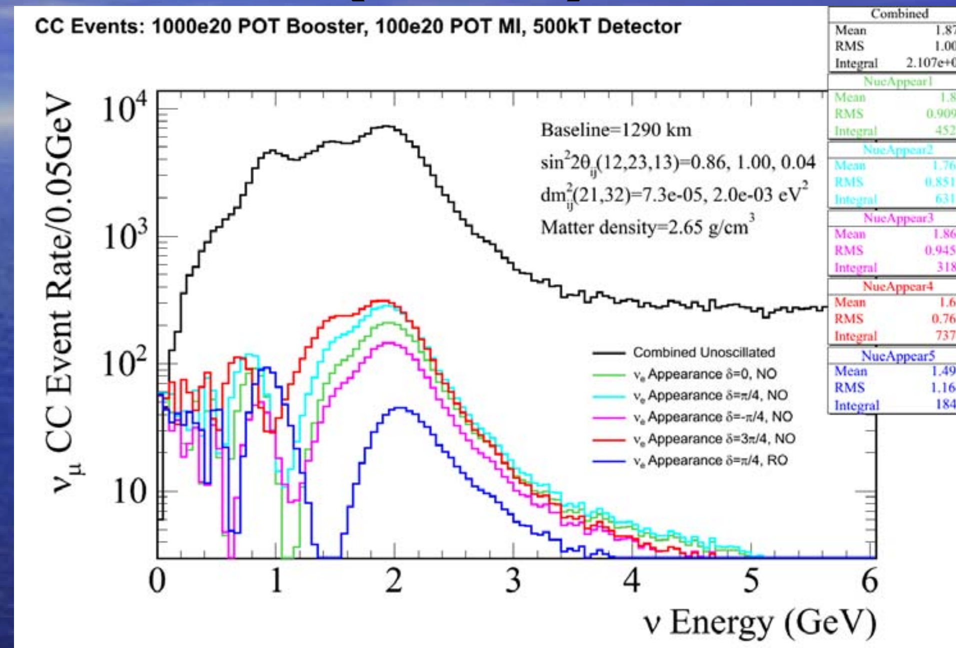
500kton
Water C
1290km
Uses all the protons from
- Booster
- Main Injector

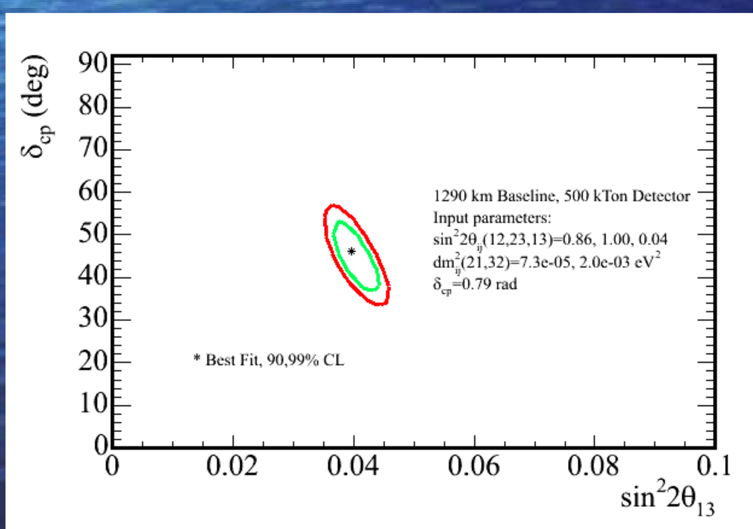




Fermilab to Homestake (2+2)MW







90% CL
99% CL

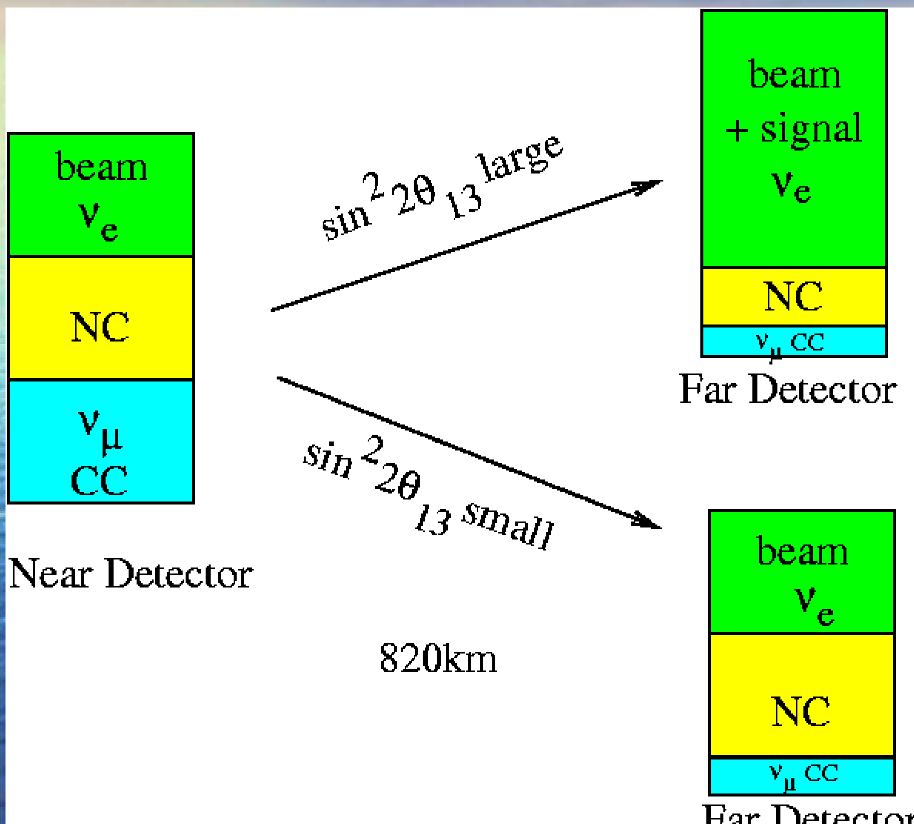
Session III

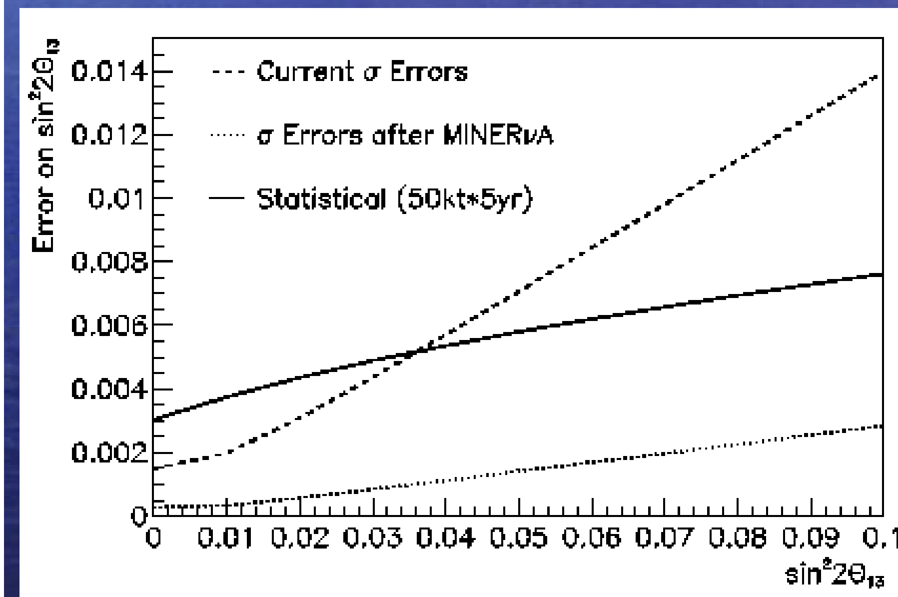
Neutrino beams
(together with WG2:
to be discussed there)

Session IV

Cross section needs
(together with WG 2)

The Cross-Section Needs of Future Oscillation Experiments (Harris)

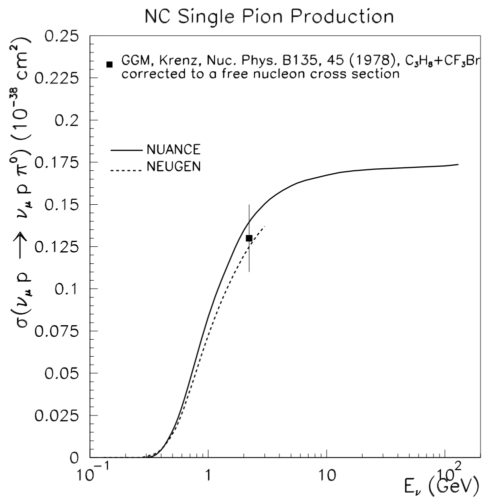


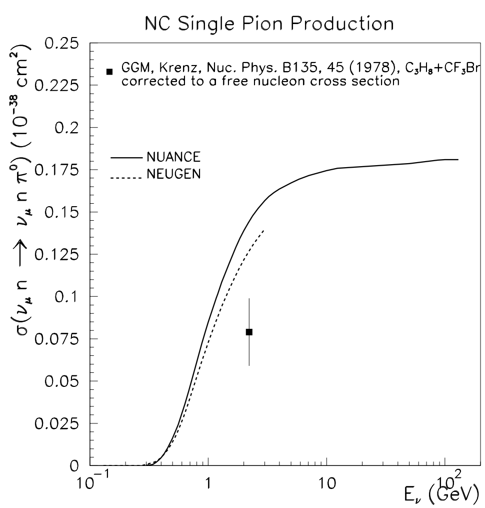


Moral of Story: Need Near Detector AND cross section measurements!

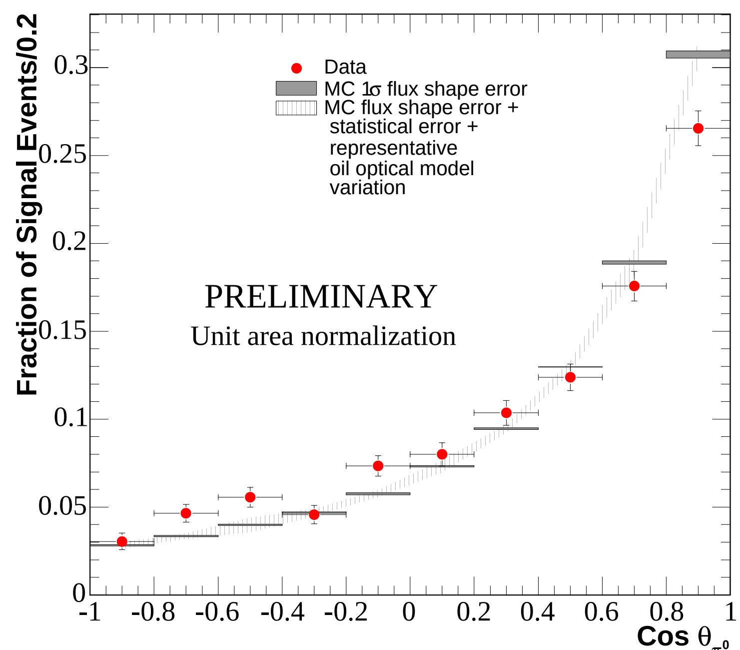
The world's NCπ^0 cross-section measurements
(the dominant background in ν_e appearance)

Status of Neutrino Cross Sections (Zeller)

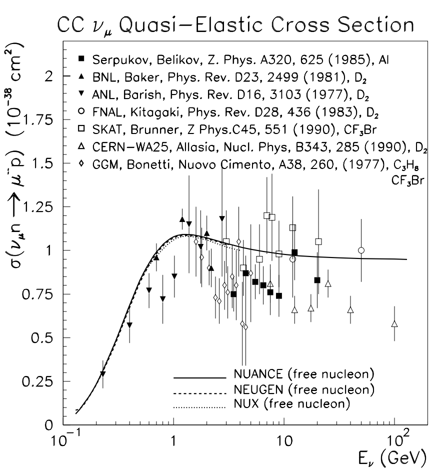




J.Raaf, MiniBooNE
~7000 events



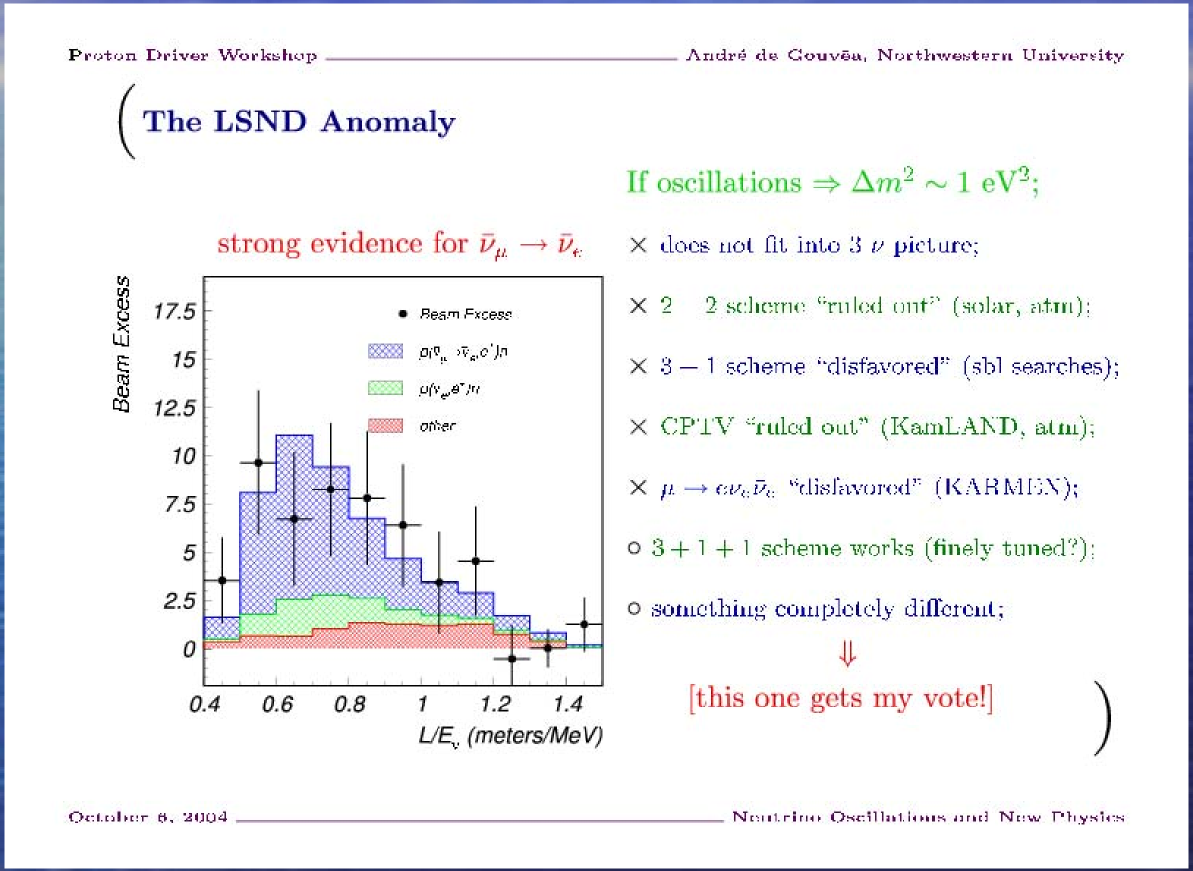
Best measurements:
CC QE



Session V

What if MiniBOONE confirms LSND?

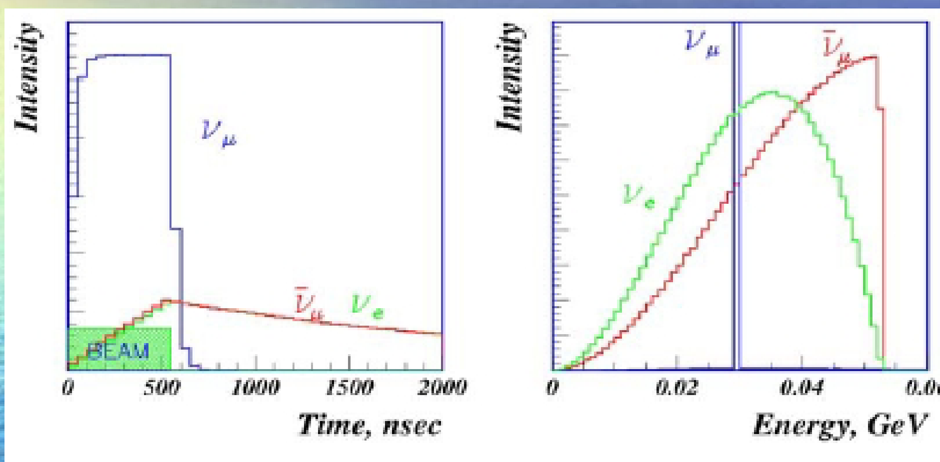
… does it have to be steriles?

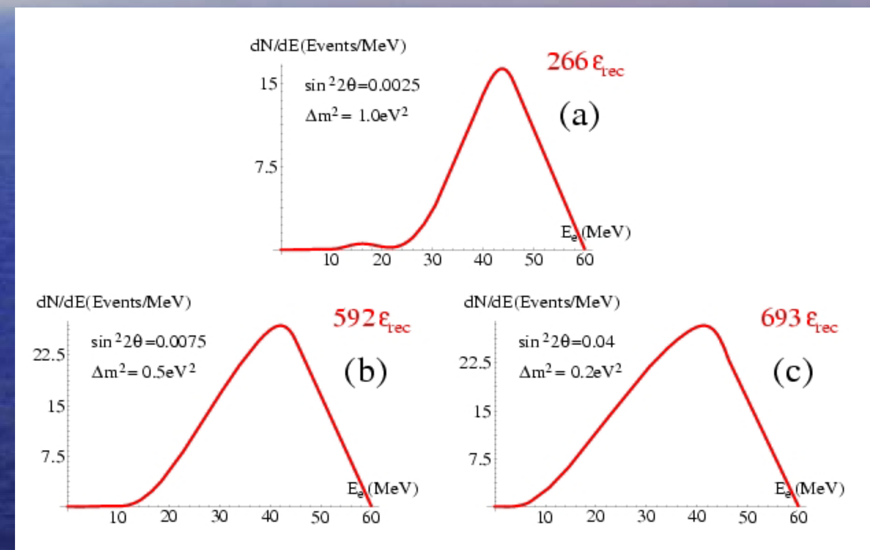


If there is a signal, test SBL further …

Decay at Rest Source (Van de Water)

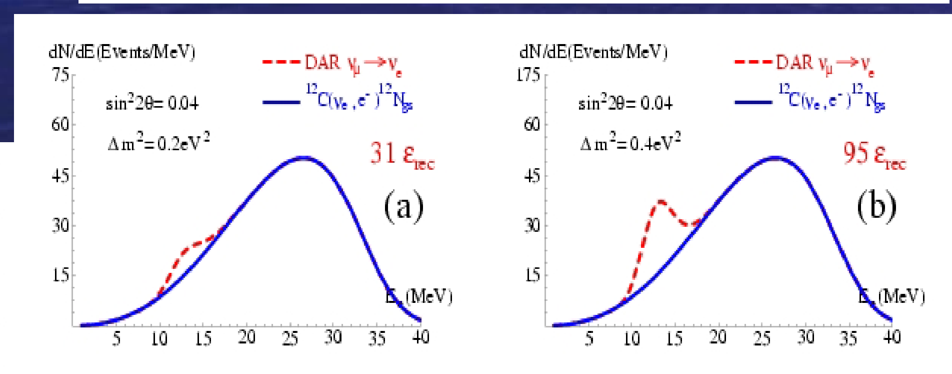
Idea: Use stopped pions and muons to better predict spectrum
=LSND with higher intensity and much larger duty factor





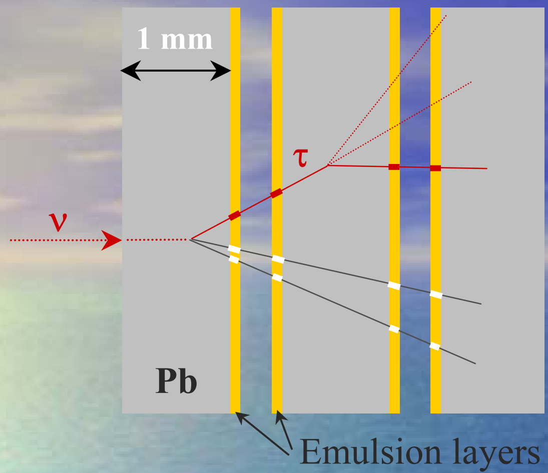
nucl-ex/0309014
hep-ex/0408135

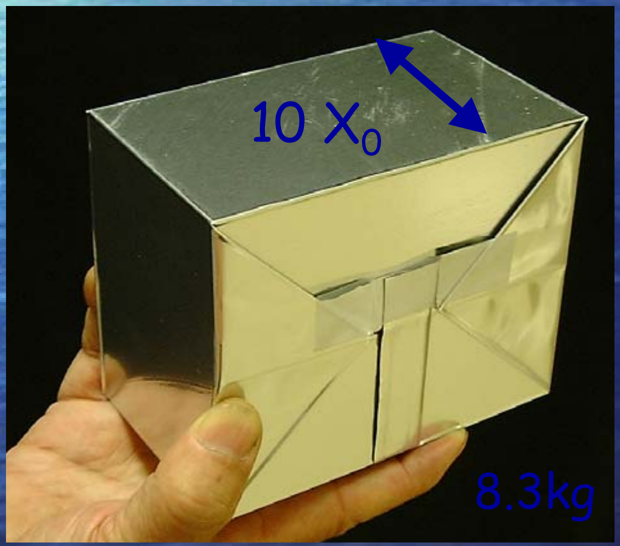
	FNAL (8 GeV)	FNAL (5 GeV)	SNS
P/yr	4.9×10^{22}	4.9×10^{22}	2.2×10^{23}
DAR $\nu(\nu/P)$	1.5	0.9	0.13
DAR $\nu(\nu/yr)$	7.3×10^{22}	4.4×10^{22}	2.9×10^{22}



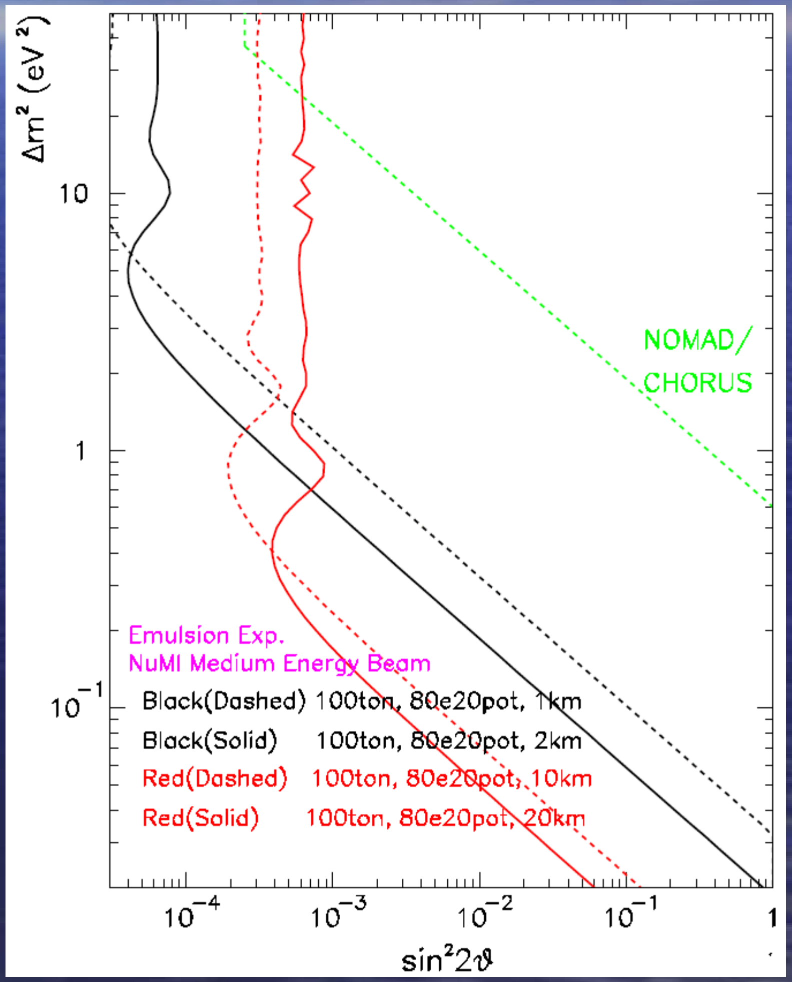
Check unitarity of mixing matrix:

NuMI numu to nutau (Bazarko)





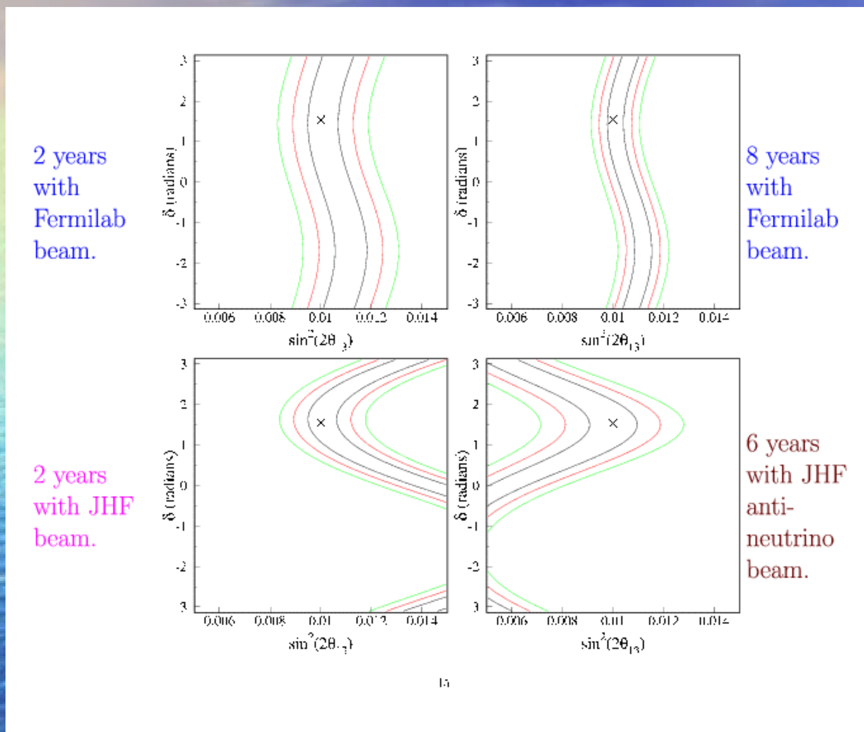
10.2 x 12.7 x 7.5 cm

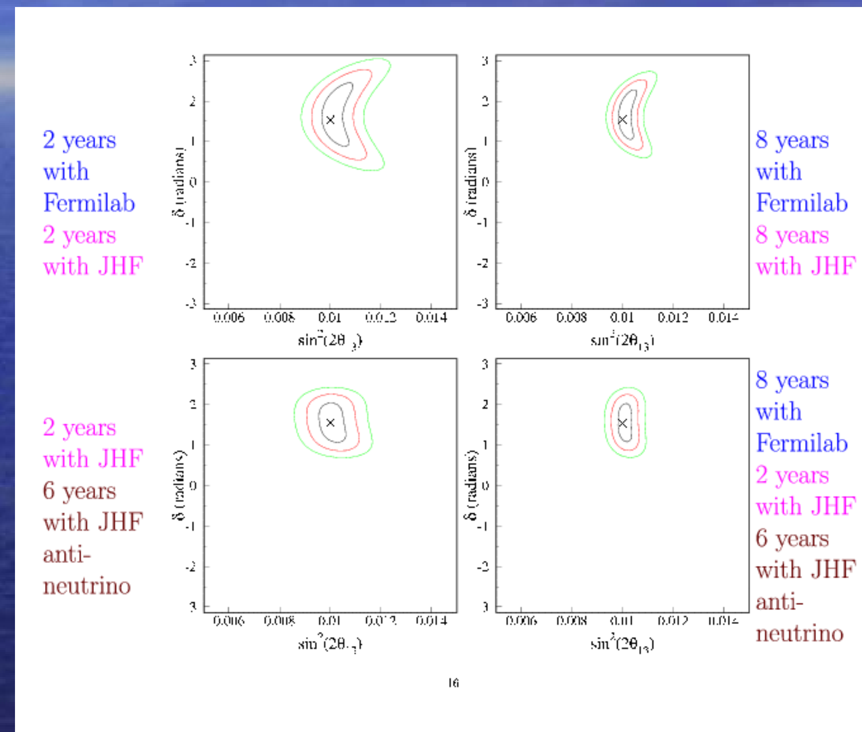


Session VI

Superbeam Experiments II

FNAL-Japan/China (Fritz deJongh)

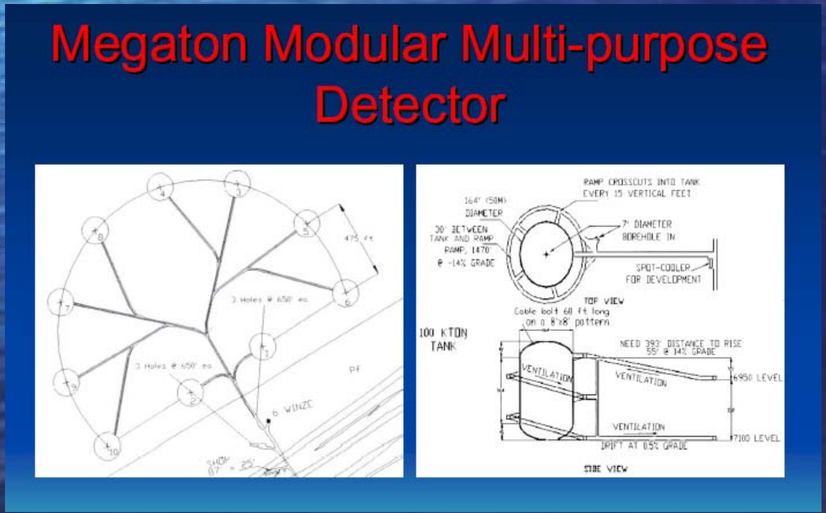


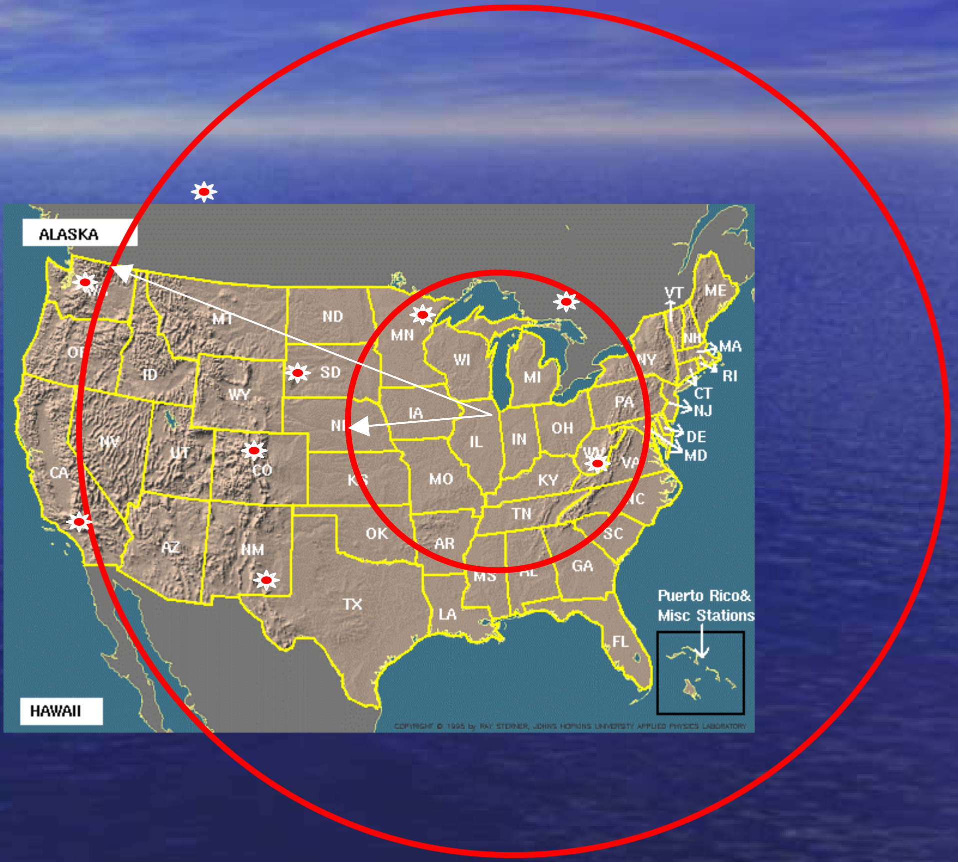


- Very long baseline good for Θ_{13} ("Magic baseline" = about 7400 km)
- Together with short baseline very good resolution for δ_{CP}

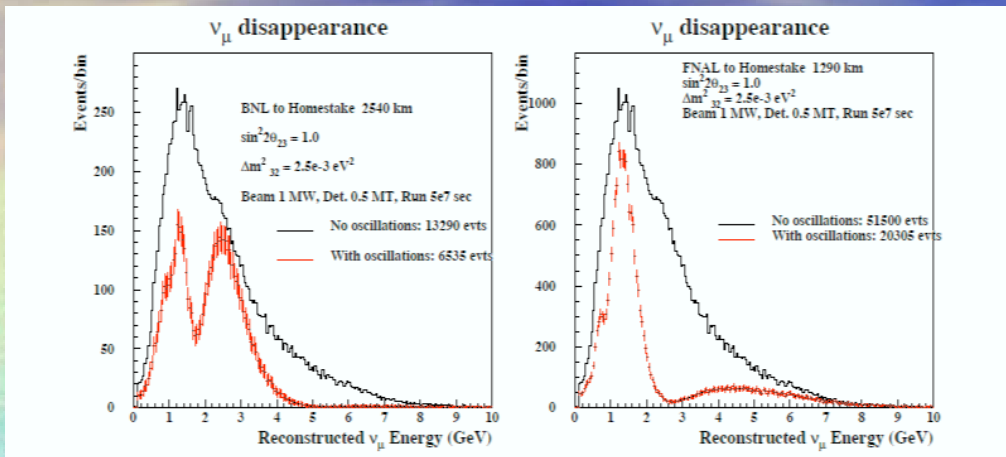
PD connection with national underground Lab (G. Rameika)

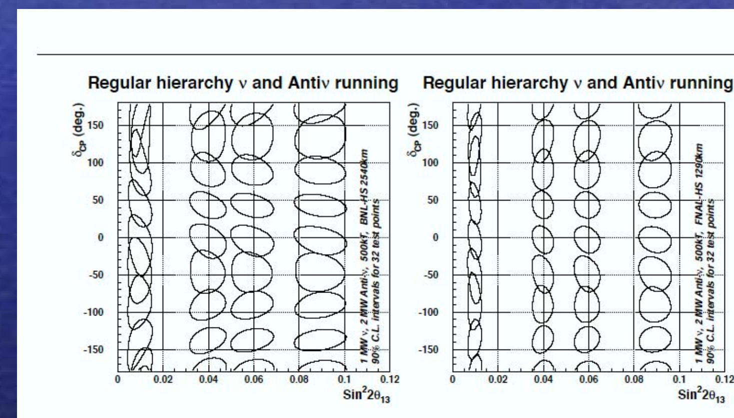
- Need for underground lab from proton decay, Dark matter searches …
- Massive detector good destination for long-baseline neutrino beams -> Synergy!

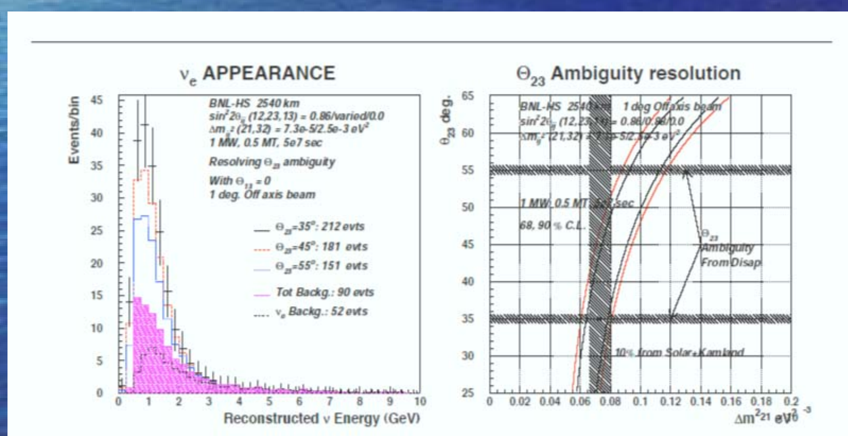




BNL- vs. FNAL- to Homestake (Diwan)







- FNAL-Homestake very competitive for Θ_{13} and also δ_{CP}
- BNL-Homestake has more solar oscillation contribution!

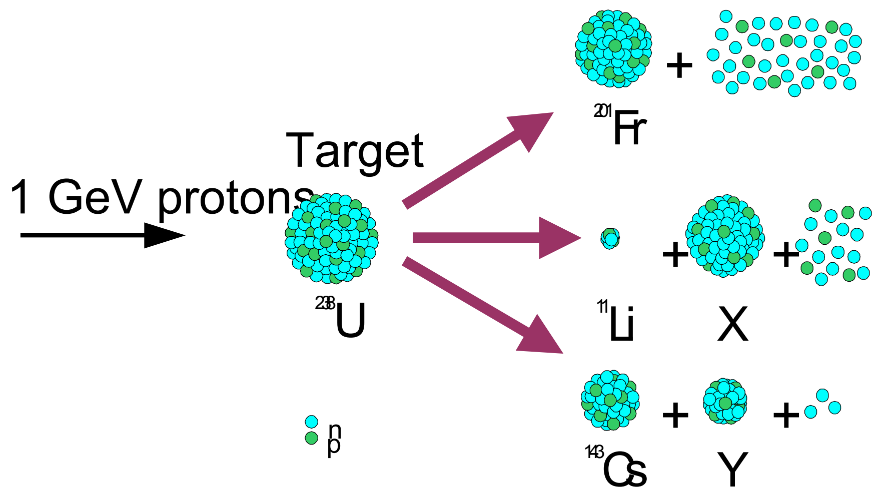
Session VII

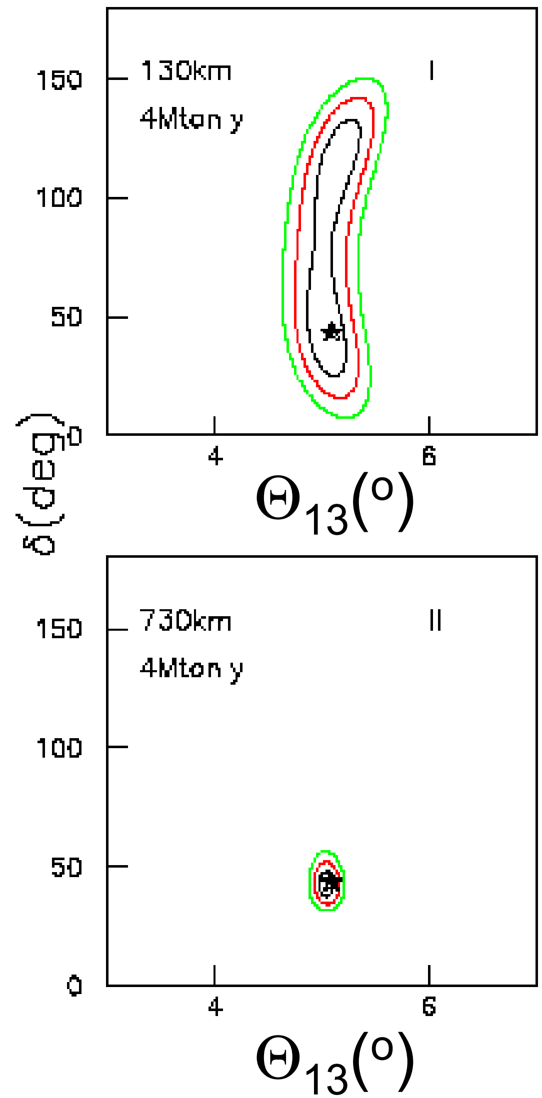
β-Beam at Fermilab?

Beta-Beams (Jansson)

${}^{6}_{2}He \rightarrow {}^{6}_{3}Li\, e^{-}\,\overline{\nu}$ ${}^{18}_{10}Ne \rightarrow {}^{18}_{9}Fe\, e^{+}\,\nu$

$\text{Average}\, E_{cms} = 1.937\, \text{MeV}$ $\text{Average}\, E_{cms} = 1.86\, \text{MeV}$

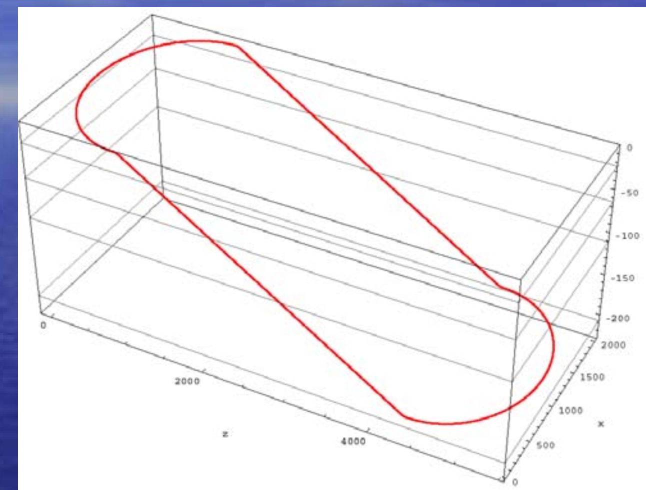




Burguet-Castell *et al,* Nucl.Phys.B695:217-240,2004.

- Use about 250kW per Ion source (for ν and $\overline{\nu}$ running simultaneously)
- Decay losses need study (quenching? Mokhov in January …)
- About 1 10^{13} ions of either type per cycle should yield an average loss power of about 1 W/m in Tevatron.

Site Constraints of Beta-Beam at FNAL



"Stretched Tevatron" aimed at Soudan

Total circumference: approximately 2 x Tevatron

320m elevation @ 58 mrad

26% of decays in Straight Section

Draft Table of Contents

Summary and conclusions

- Interesting discussions:
  - Staged approach versus one big jump
  - Importance of long distance for "solar" terms
  - Parallels with collider program?
  - …
- Homework assignments
  - Writing for everybody
  - Gary Feldman will look at fluxes from 8 GeV protons to NOvA
  - How statistics limited is the NOvA theta23 measurement?
  - …

Thanks to all our great speakers!